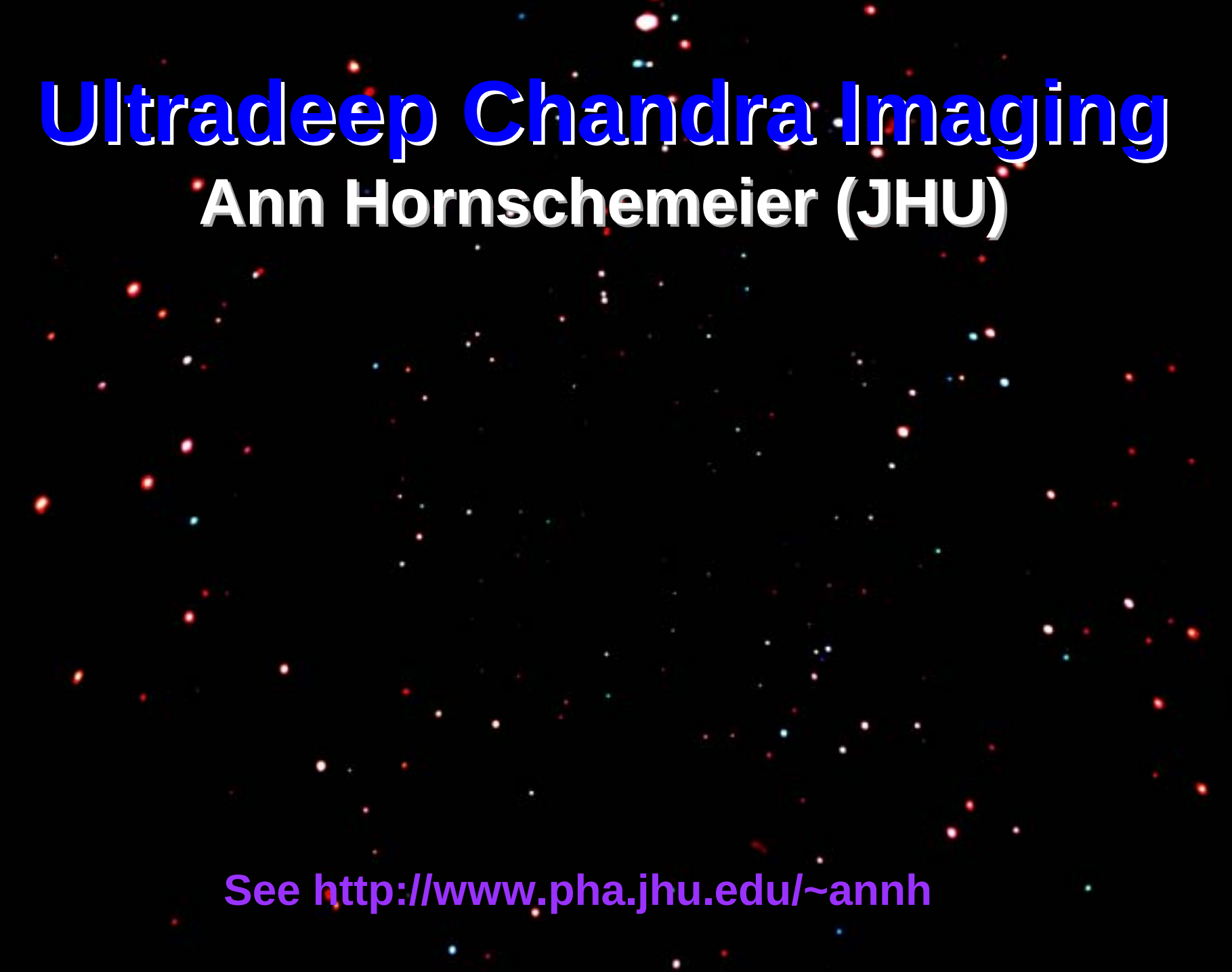
Ultradeep Chandra Imaging

Ann Hornschemeier (JHU)



See http://www.pha.jhu.edu/~annh

Ultra aging

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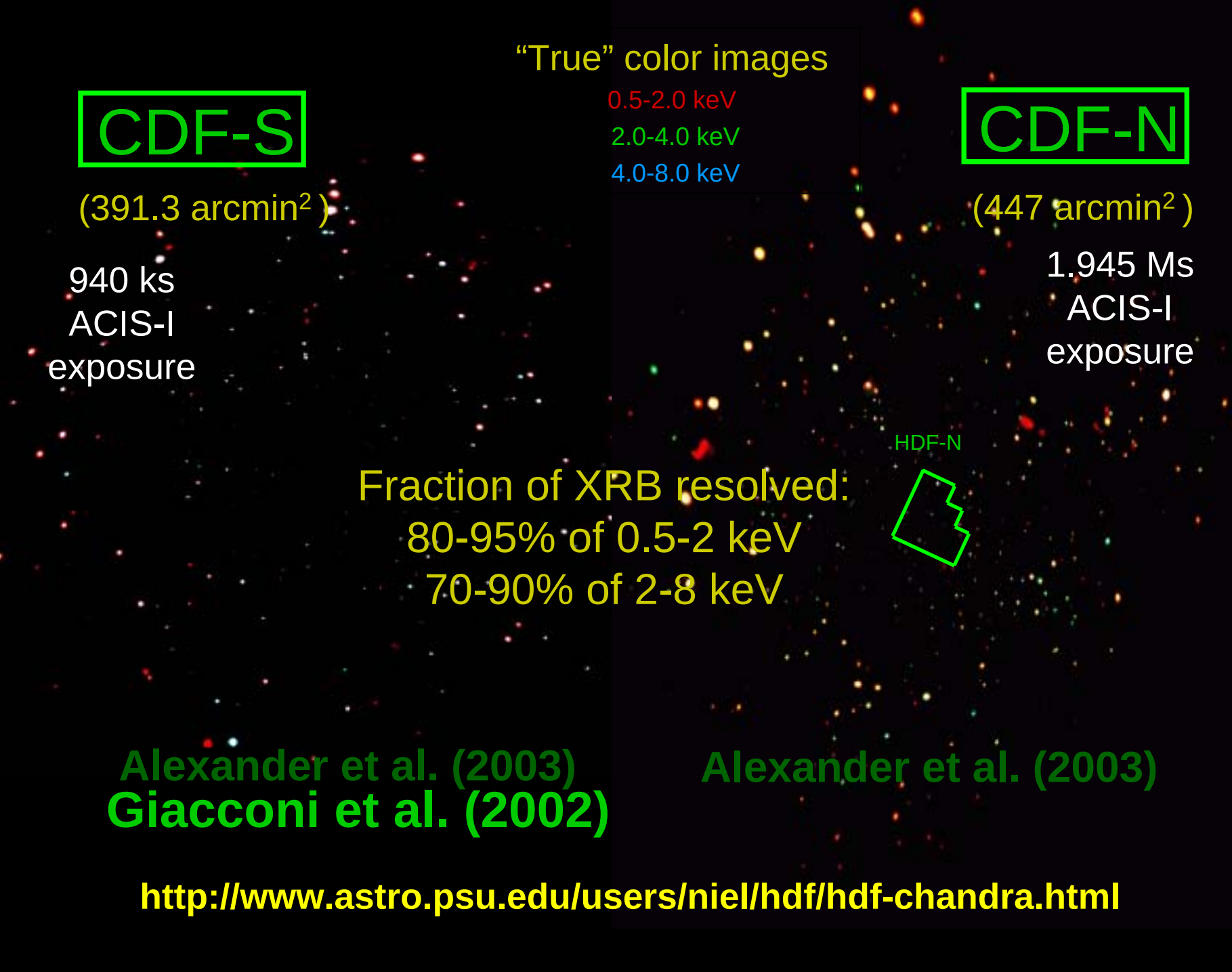

"True" color images
0.5-2.0 keV
2.0-4.0 keV
4.0-8.0 keV
CDF-S
(391.3 arcmin^2)
940 ks
ACIS-I
exposure
CDF-N
(447 arcmin^2)
1.945 Ms
ACIS-I
exposure
HDF-N
Fraction of XRB resolved:
80-95% of 0.5-2 keV
70-90% of 2-8 keV
Alexander et al. (2003)
Giacconi et al. (2002)
Alexander et al. (2003)
http://www.astro.psu.edu/users/niel/hdf/hdf-chandra.html

GOODS =

Great Observatories Origins Deep Survey

HST ACS DATA

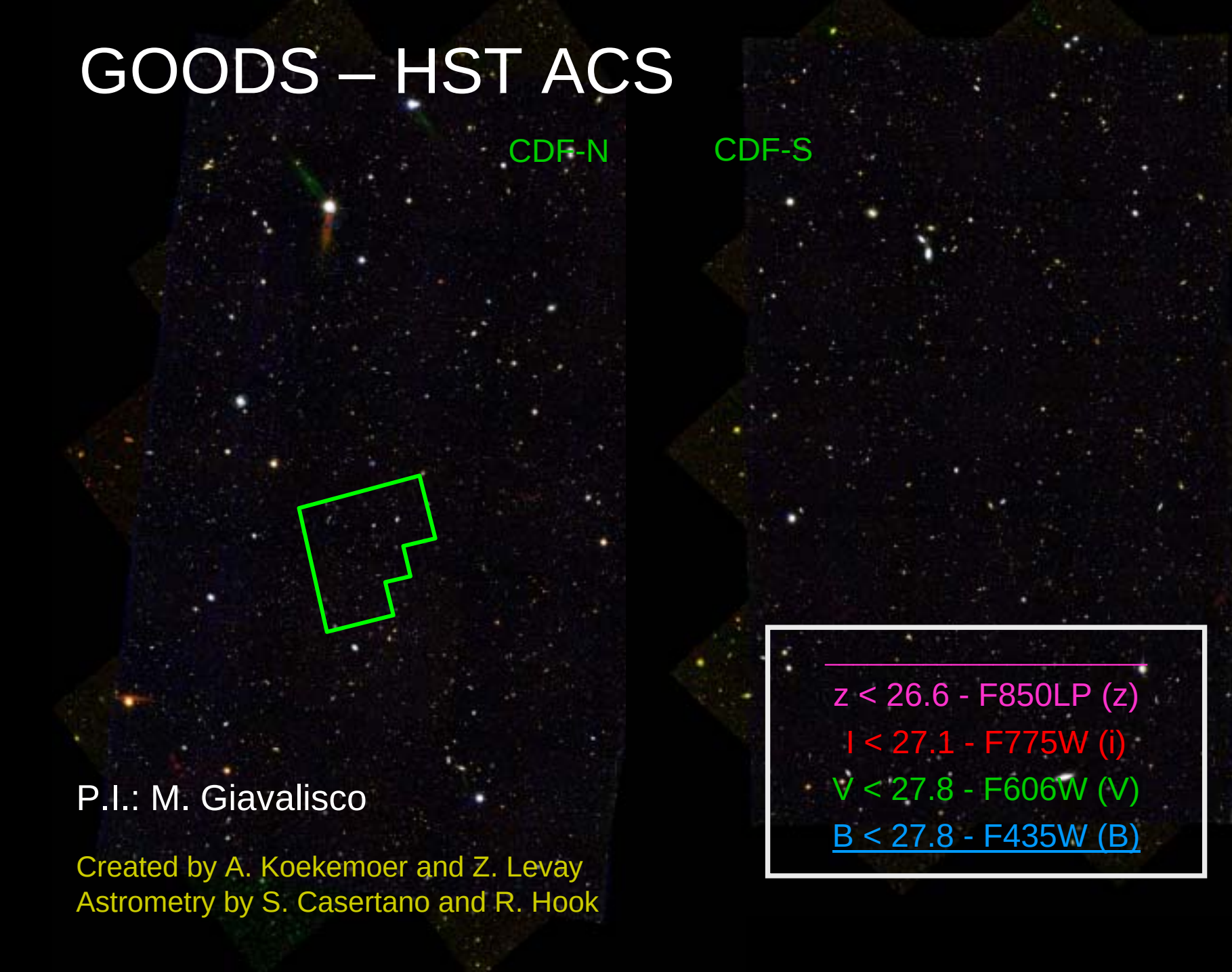
P.I. Mauro Giavalisco (ACS)

320 sq arcmin 30-observation mosaic

(38% of CDF area)

http://www.stsci.edu/science/goods/

GOODS – HST ACS



z < 26.6 - F850LP (z)

I < 27.1 - F775W (i)

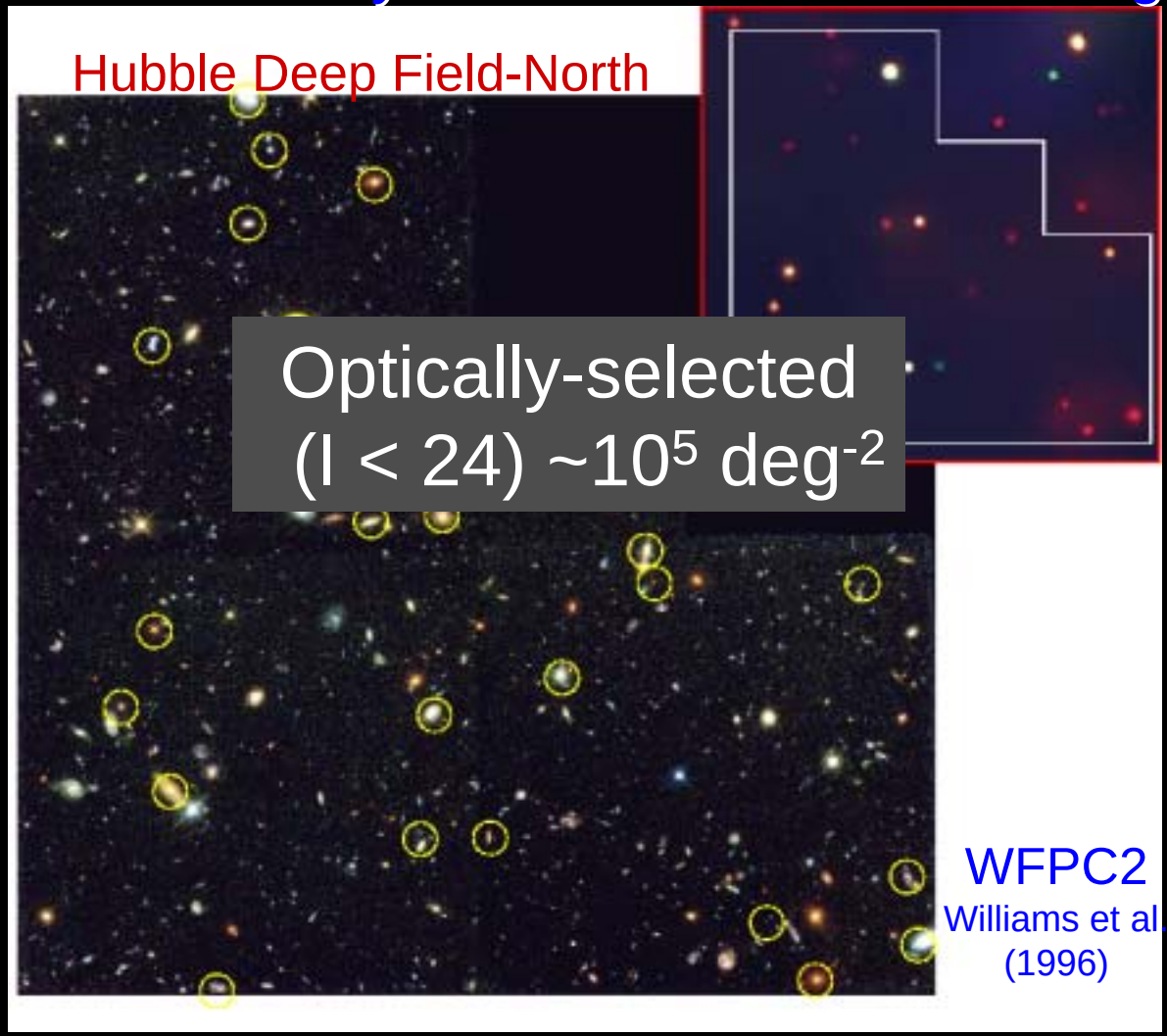
V < 27.8 - F606W (V)

B < 27.8 - F435W (B)

P.I.: M. Giavalisco

Created by A. Koekemoer and Z. Levay
Astrometry by S. Casertano and R. Hook

Source density: 13600 ±3400 sources deg^{-2}



Alexander et al. (2003)

http://www.astro.psu.edu/users/niel/hdf/hdf-chandra.html

Star Formation/Galaxy Formation

- SFR – SMBH Connection at High *z*
  - 850 μm sources (submillimeter sources)
  - Host galaxy/SMBH connection at high-z
- X-ray – SFR Connection
  - X-rays as an SFR Indicator
  - ULXs at z=0.1
  - “Normal Galaxy” XLF at z > 0.1
- Galaxy X-ray Emissivity over Cosmic Time
  - Spirals & elliptical galaxies
  - Normal Galaxy Number Counts

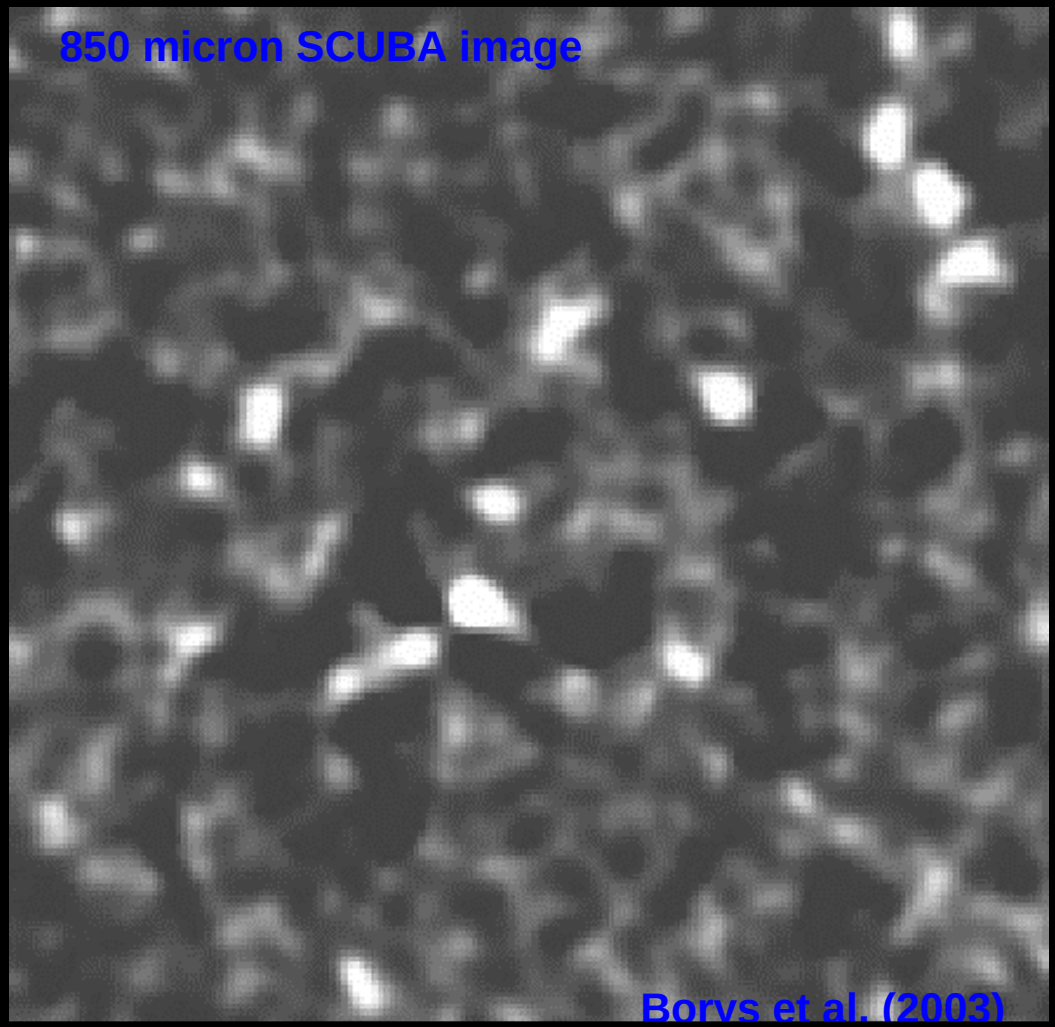
SFR-AGN Connection at high *z*: Submillimeter (850 μm) sources

Dusty high-redshift starburst galaxies

< 250 ks Chandra surveys →
little overlap with 850 μm (submm) source population

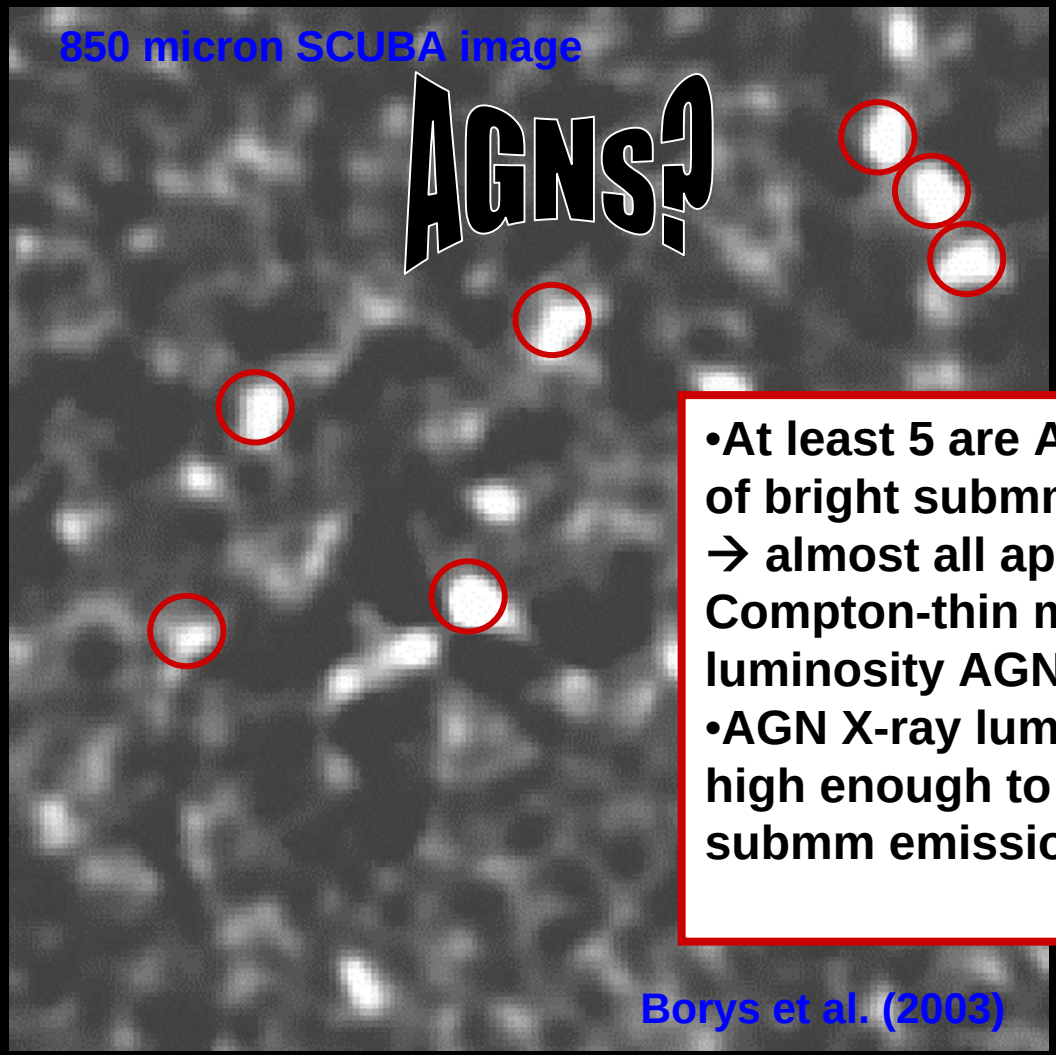
(e.g., Fabian et al. 2000; Severgnini et al. 2000; Hornschemeier et al. 2000, 2001; Bautz et al. 2001; Barger et al. 2001)…

SFR-AGN Connection at high *z* : Submillimeter sources



13 S/N>4 SCUBA galaxies with f(850μm)>5 mJy (Borys et al. 2003)

SFR-AGN Connection at high *z* : Submillimeter sources



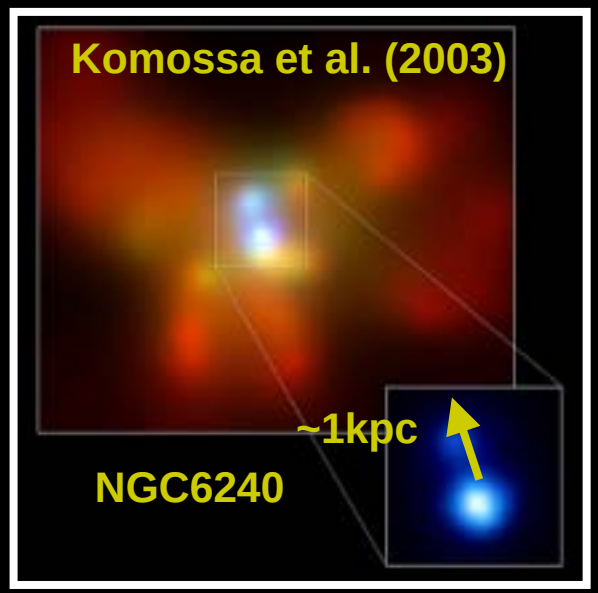
- At least 5 are AGNs (38% of bright submm galaxies) → almost all appear to be Compton-thin moderate-luminosity AGNs
- AGN X-ray luminosity not high enough to power submm emission

7 (54%) of the sources are X-ray detected (Alexander et al. 2003)

SFR-AGN Connection at high *z* : Submillimeter sources

2/7 (30%) submm galaxies with close X-ray pairs (<3”) vs 5/193 (3%) over whole field (see also Smail et al. in prep)

Binary AGN?



Link between binary AGN and Dusty starburst galaxies?

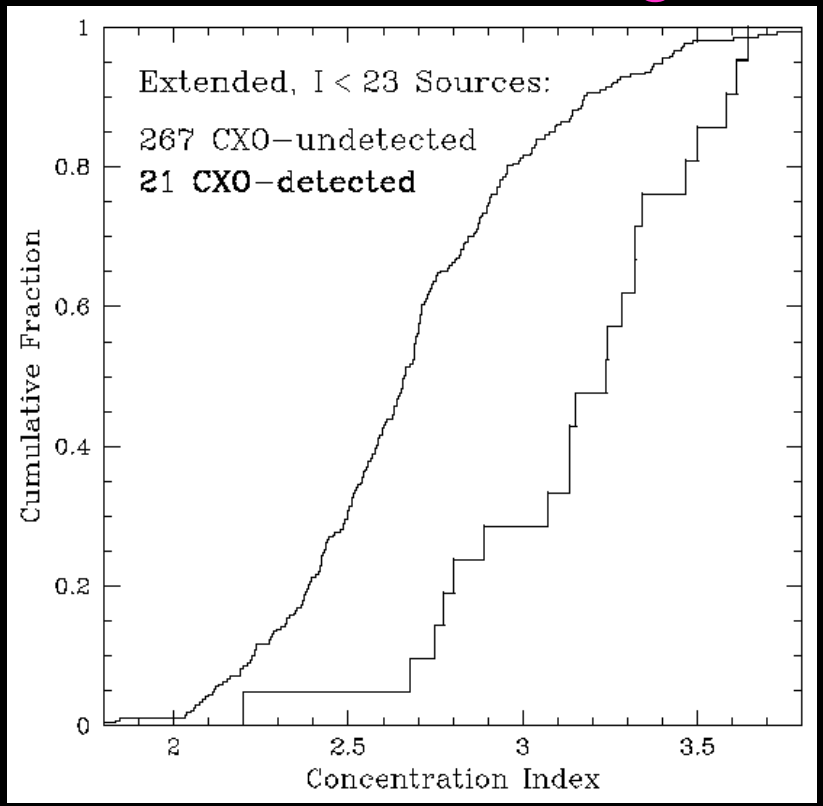
SFR-AGN Connection at high *z* : SMBH-Galaxy Structure Relationship

What is the role played by the SMBH in forming galaxies?

- **Locally, tight correlation between SMBH mass and:**
  - **Host galaxy velocity dispersion**
    (e.g., Gebhardt et al. 2000; Ferrarese & Merritt 2000)
  - **Morphological concentration of host galaxy**
    (e.g., Graham et al. 2001)

SFR-AGN Connection at high *z* : SMBH-Galaxy Structure Relationship

Grogin et al. 2003a

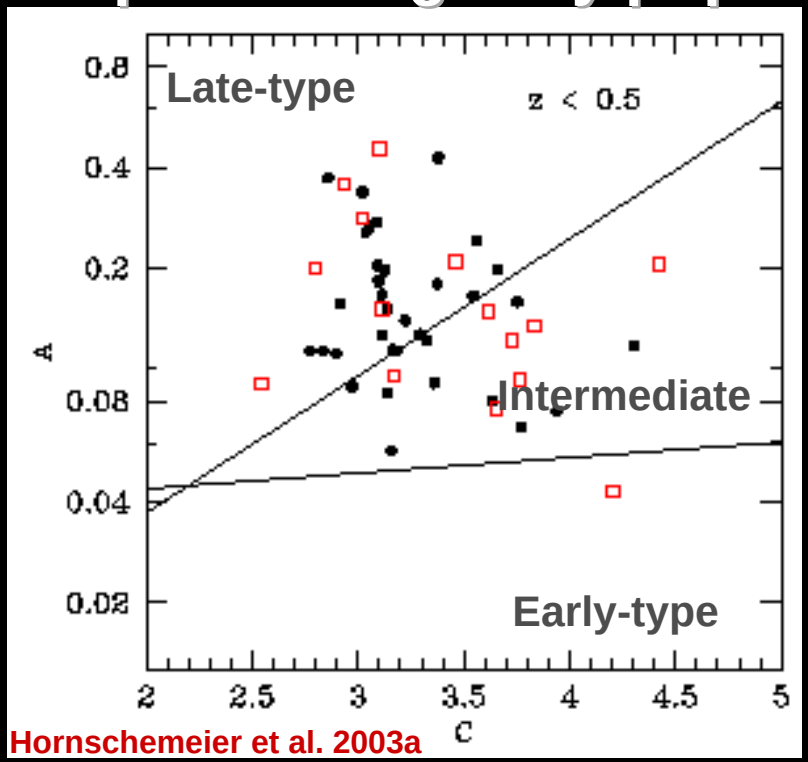


- The locally-observed relation between SMBH mass and host galaxy properties is already in place by z~1

- Asymmetry indices appear consistent but statistical constraints not as strong
- Link between mergers & AGN fueling??

SFR-AGN Connection at high *z* : SMBH-Galaxy Structure Relationship

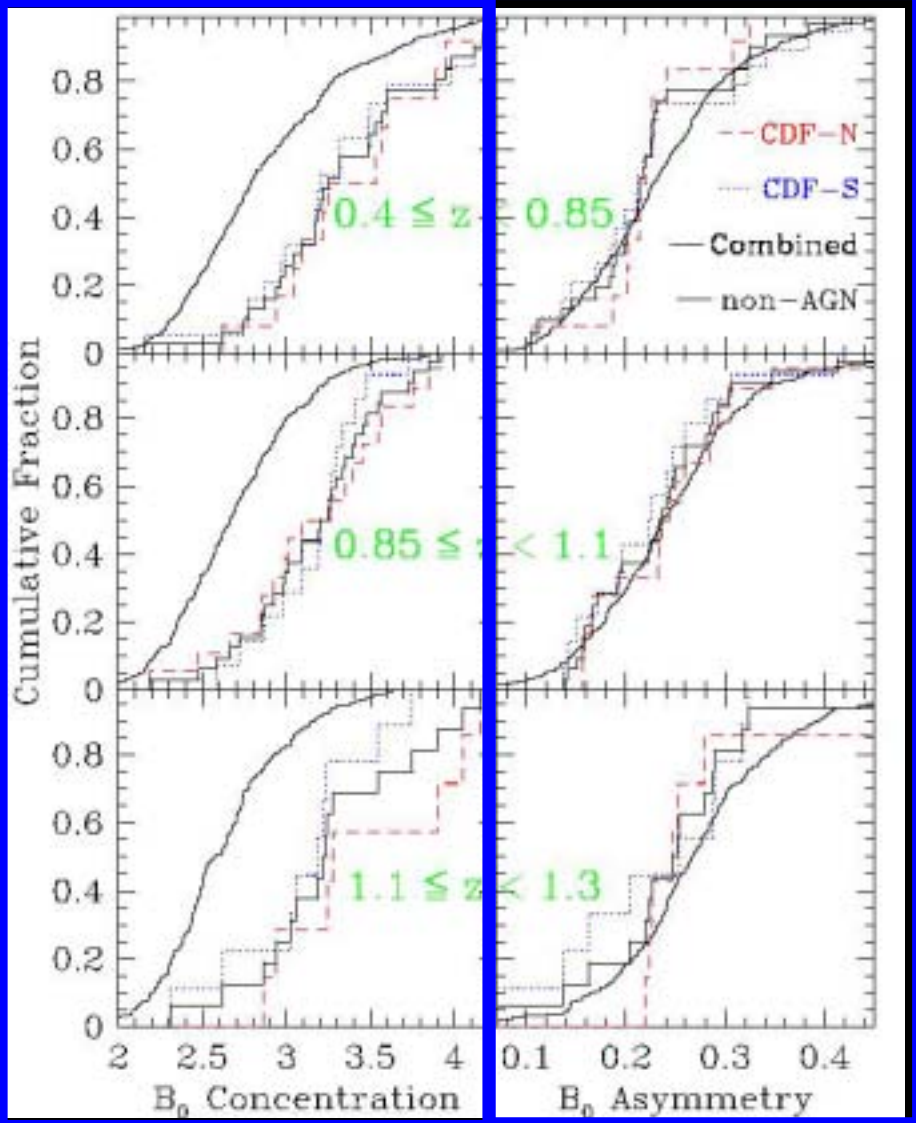
Need to unambiguously separate AGN/quiescent galaxy population



Hornschemeier et al. 2003a

Asymmetry and concentration indices of quiescent galaxies statistically indistinguishable from field-galaxy population (Hornschemeier et al. 2003)

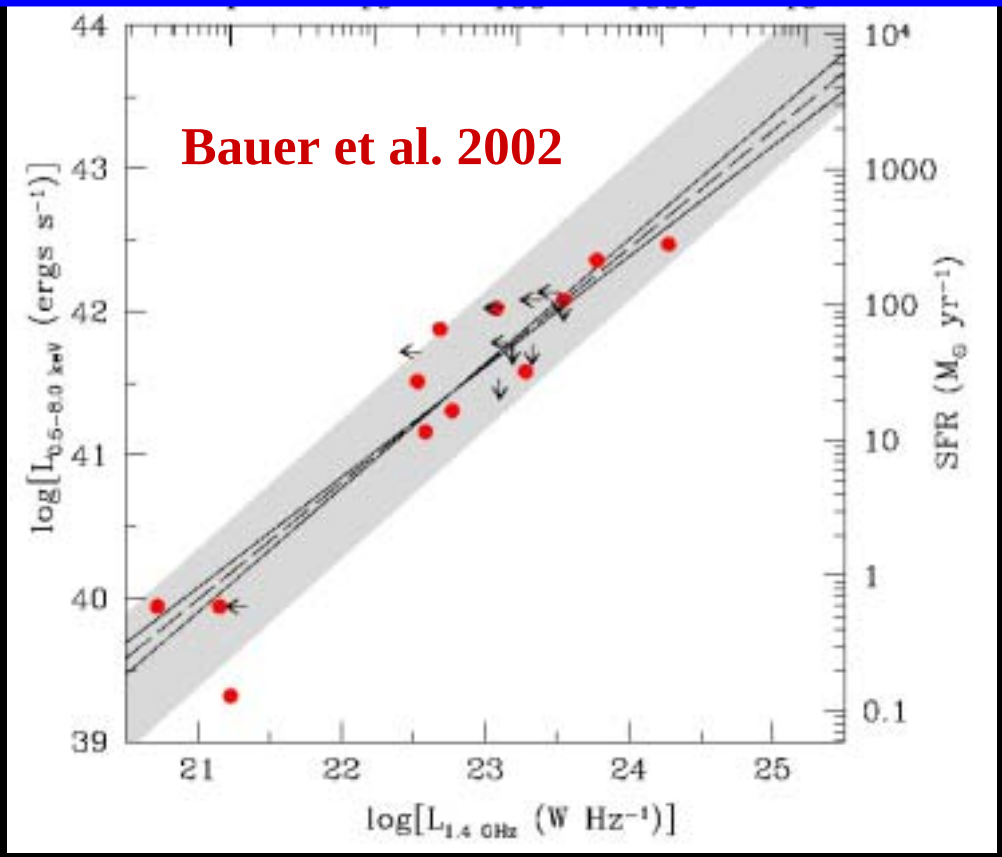
SFR-AGN Connection at high *z* : SMBH-Galaxy Structure Relationship



- ACS GOODS data → > 50 galaxies, $L_{2\text{-}8\ keV} > 10^{42}$ erg s^{-1} (Grogin et al. 2003b)
- Higher concentration of AGN hosts confirmed

- Recent merger history does not predict AGN activity
- If mergers linked to AGN fueling, timescales are > 1 Gyr (Grogin et al. 2003b)

X-ray-SFR Connection: Radio/FIR – X-ray Correlations



0.5-8 keV luminosity may be an SFR indicator

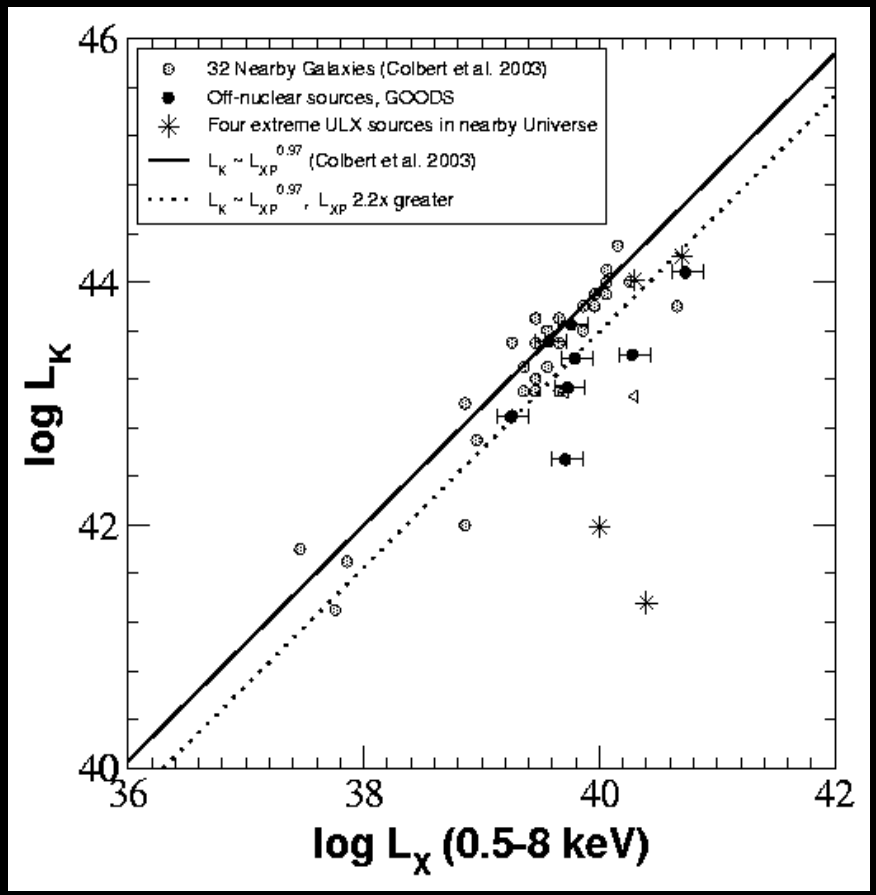
(Bauer et al. 2002, Seibert et al. 2002, Ranalli et al. 2002, Nandra et al. 2002, Grimm et al. 2002, Cohen et al. 2003)

X-ray-SFR Connection: ULX Population at z=0.1

- 12 highly confident ULX sources in GOODS fields
- ACS BVIz → Stellar masses & SFR history (Bruzual & Charlot models)

Hornschemeier et al. (2003b)

X-ray-SFR Connection: ULX Population at z=0.1 (GOODS)



- K-band luminosity as proxy for galaxy mass
- When ULX is present in local galaxies, generally dominates L_{XP}
- For galaxies of comparable mass, ULX hosts L_X ~2.2 times higher than local L_{XP} (Colbert et al. 2003)
- GOODS galaxies have higher SFR, elevation may be explained by elevated SFR at z=0.1
- Will soon have SIRTF data to more accurately characterize SFR

Hornschemeier et al. (2003b)

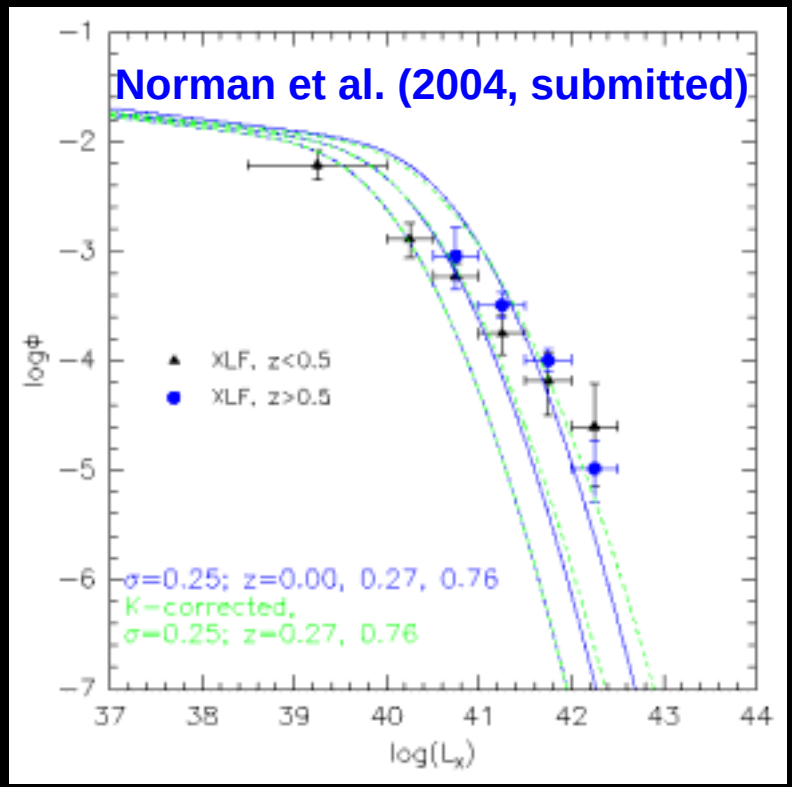
X-ray-SFR Connection: "Normal Galaxy" XLF at z>0.1

Norman et al. (2004, submitted)

- 1 Ms spectroscopic coverage now complete enough (Barger et al. 2002, Szokoly et al. 2003)
- 47 galaxies in CDF-S, 62 galaxies in CDF-N:
  - Optical spectra → emission line ratios, lack of AGN features
  - X-ray hardness and X-ray Luminosity Bayesian selection technique using confident candidates to construct prior, (A. Ptak's talk this morning)

X-ray-SFR Connection: "Normal Galaxy" XLF at z>0.1

- Little evolution of normal galaxy XLF up to z~1
- Bayesian selection technique demonstrates that L_X/HR effective at selecting normal galaxies
- Recover consistency with IR LF when using XR/IR relations (e.g., Ranalli et al. 2002)

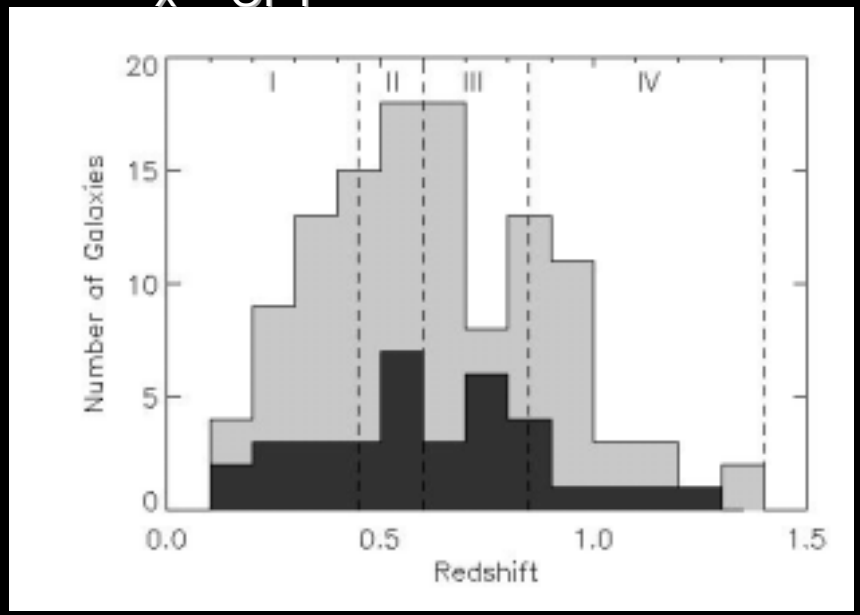


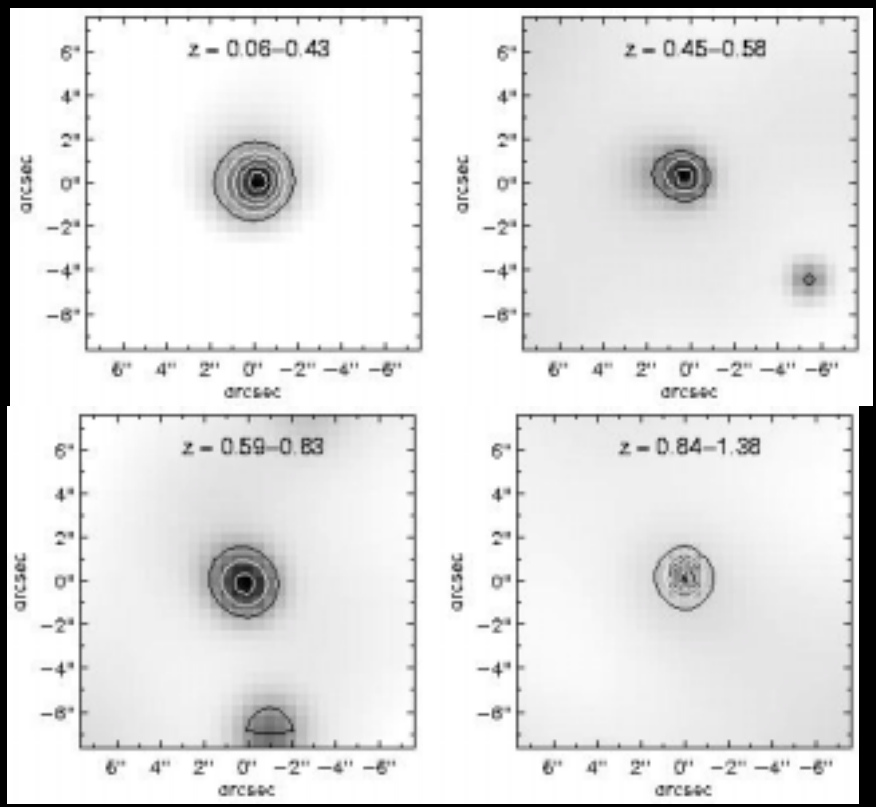
X-ray Emissivity of Galaxies : Spiral Galaxies

- Probe X-ray binaries over timescales much longer than achievable in nearby Universe (e.g., White & Ghosh 1998)
- Hornschemeier et al. (2002) placed constraints on the X-ray evolution of spirals, increase by at most factor of 2 by z=1.0
- Recently more accurately calibrated in the wider-field *XMM*/2dF survey (z=0.1, Georgakakis et al. 2003)
- Very exciting upcoming observations: the wide-field "E-CDF-S" survey (P.I. Brandt)

X-ray Emissivity of Galaxies : Elliptical Galaxies (Immler et al. 2003)

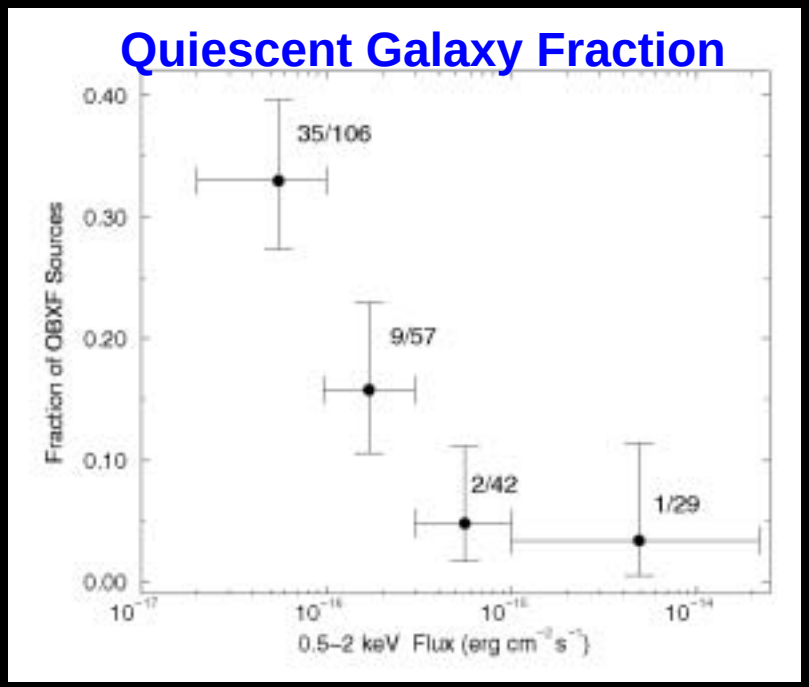
- 120 individually undetected, 40 detected
- Significant detections from $0.06 < z < 1.38$
- 1.6×10^{41} erg/s (z=1)
- L_X/L_{OPT} constant to z~1





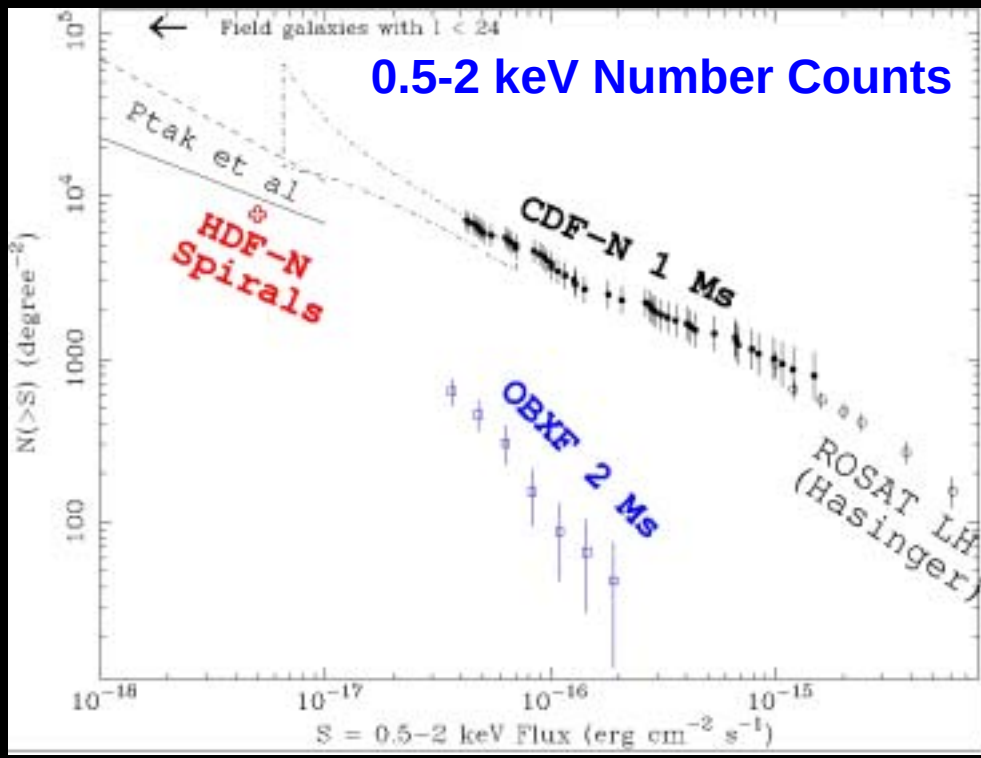
- X-ray components of ellipticals largely in place by z=1

X-ray Emissivity of Galaxies :
Steeply Rising Normal Galaxy Number Counts



- Below 3 x 10^{-16} erg cm^{-2} s^{-1}, ~30% of X-ray sources are galaxies

Hornschemeier et al. (2003a)



- Contribution to the XRB constrains SFR evolution $(1+z)^k$
- $k < 3$ (e.g., Georgakakis et al. 2003)

SUMMARY

- Energetics of dusty high-*z* starbursts (850 μm sources) not dominated by accretion activity (Alexander et al. 2003b)
- Host galaxy/SMBH relations in place by z~1 (Grogin et al. 2003)
- z=0.1 ULX properties explained in terms of elevated SFR/local point source properties (Hornschemeier et al. 2003b)
- "Galaxy" XLF at z > 0.1 **(Norman et al. 2004)**
- Spirals exhibit modest evolution, *z*=0.1-1.0 (Hornschemeier et al. 2003a, Georgakakis et al. 2003)
- X-ray components of elliptical galaxies in place by *z*=1 (Immler et al. 2003)

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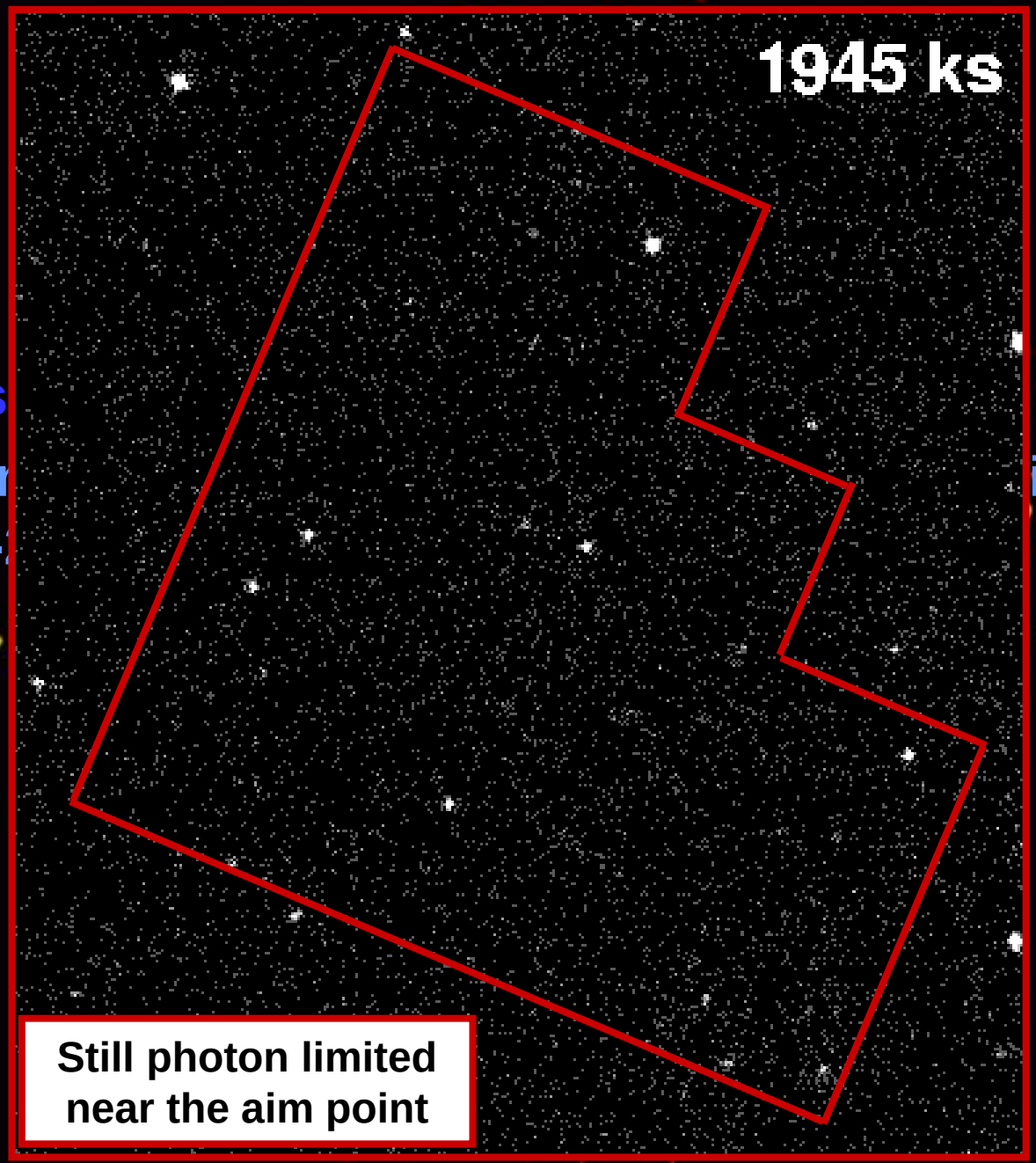

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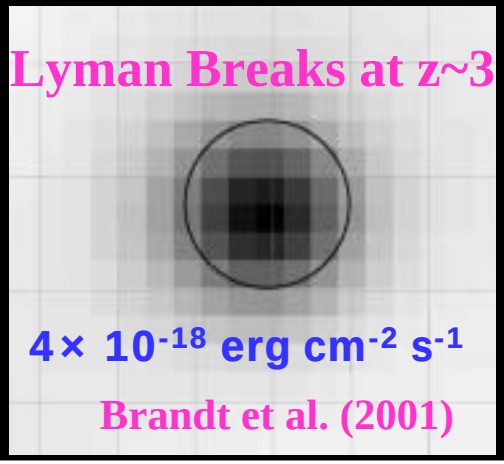
5-10 Ms: What will we see?

- Starburst galaxies up to z~3
  - Directly probe SFR evolution



- In HDF-N
  - 50-100 galaxies
- Within GOODs area
  - 400+ galaxies

- Through stacking:
  - probe at least 5-10× deeper
  - 10,000 galaxies
- Stellar-mass black holes
  - Plausibly expect 20—30

•Confusion at ≈2× 10^{-18} erg cm^{-2} s^{-1} for 2.0" spatial resolution

•5-10 Ms Chandra survey is the most direct way to evaluate before